MINDDA and Stochastic Modeling of the Seismic Stratigraphy of a Mixed Carbonate-Siliciclastic System: High-Resolution Geophysics at the SCS ASIAEX Site

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LONG-TERM GOALS

Our research group is collecting and analyzing various levels of high-resolution seismic data, along with cores, for ground-truthing seismic facies on continental margins with a spectrum of depositional boundary conditions. The long-term goal of this work is to develop stochastic models of variation of geotechnical and seismic property distribution on margins subjected to a spectrum of depositional regimes. We are also assessing the quantity of data required to recognize the nature of stratigraphic architecture of a continental margin. We refer to this as Minimum Data Density Analysis (MINDDA). The importance of being able to produce these stochastic models is that it provides a means of making predictions (with assignment of statistical risk) of the variation of geotechnical and seismic properties in areas where the only data that may exist for that margin at the time that a prediction is needed is information on physical oceanography or other gross descriptions of depositional conditions on the margin. In the ECS we have a regional data set that we are using for this purpose and we have initiated MINDDA and it appears as though we have established MINDDA for a number of stratigraphic elements of the East China Sea continental margin. The data acquisition and analysis program in the ECS provides control and the background data set required for the 2001 ECS ASIAEX acoustics experiment that is geared toward improvement of understanding of bottom interaction and sound propagation in continental margin environments.

As part of this project we were also supposed to conduct a study in the South China Sea (SCS) in 2000. The SCS work was to provide geological constraints on bottom interaction for the ASIAEX volume interaction experiment in the area. It also would have assisted us in our attempt to understand linkages between environmental conditions and stratigraphic architecture variability by providing an opportunity to analyze a margin subjected to conditions that lay between the end-members we have been studying. International politics led to the loss of the area clearances we had to work in the ECS and SCS in 2000. Negotiations led to access to another area clearance the ECS, but not in the SCS. This project is an outgrowth of efforts to acquire the geologic data required to constrain the impact of the bottom at the SCS ASIAEX site. After much negotiation we were able to get permission in 2002 to work in the SCS in from a Taiwanese vessel in the spring (April and March) of 2003.

OBJECTIVES

•Stochastic models of the "End-Member" systems (ECS and NE GOM) indicate that the spatial distribution of seismic facies are distinctly different from one another and that there is a significant relationship between the distribution of facies and processes. In order to refine our understanding of

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these relationships and test hypotheses about process-response linkages and acoustic property distribution we also need to acquire and analyze data from margins lying between our "End-Members". Acquisition of a semi-regional – reconnaissance, nested data set consisting of geophysical data (seismic, chirp, and side-scan) and geologic data (cores) in a grid with profiles oriented parallel to depositional strike and dip within an area defined by the following coordinates (22°20'N and 117°00'W, 22°30'N and 117°50'W, 21°30'N and 117°10'W, 22°00'N and 118°20'W) on a portion of the South China Sea (SCS) continental margin provides an opportunity to establish the nature of relationships and develop stochastic models for a system with intermediate boundary conditions relative to the Gulf of Mexico site, and our ECS and Yellow Sea (YS) experiment sites. This is an objective of the research supported with this grant. The project contrasts with the other sites because there are no large rivers directly providing sediment to the system. Sediment accumulating in the area is advected into the area from the Pearl River by currents driven by monsoon winds, and by currents that flow southwest from the East China Sea. Boundary conditions that overlap with the other sites includes a tidal range (and currents) that overlaps with the NE GOM and outer ECS. Sediment transport associated with storms has a high probability of being similar to the ECS and YS because the SCS experiences frequent and intense tropical storms in the summer and fall.

It is not possible to go and study 15 East China Seas, or any other system for that matter, so we must improve our understanding of the relationship between statistically significant trends in spatial distribution of physical properties on continental margins and the distribution and magnitude of physical processes operating continental margins through analysis of these relationships using nested data sets from a range of environments. The SCS fills an intermediate niche of boundary conditions and therefore acquisition and analysis of data from this area will aid in development of a robust, stochastic, process-response model of acoustic property distribution that is linked to environmental boundary conditions and provide a background data set for understanding acoustic anomalies detected in the acoustics experiment that was conducted to test the impact of the "ocean volume" on the propagation of sound on continental margins in 2001. Due to slope instability, outer shelf and slope environments often have a large degree of spatial variability in distribution of physical properties. An objective of this research is acquisition and analysis of high resolution seismic, chirp sonar, side-scan sonar, and core data to provide control for the volume interaction experiment by isolating the nature of seafloor and sub-bottom acoustic property variability generated by slope instability.

•At the SCS ASIAEX site we proposed acquisition of approximately 2,490 km of high-resolution seismic data in the study area within a semi-regional scale survey in the SCS to provide an opportunity to test concepts about statistically significant trends in spatial variability and environmental boundary conditions. We planned to acquire data within a relatively widely spaced regional grid to establish regional trends. We proposed acquisition of a tighter grid over the ASIAEX site within a 40 by 30 nautical mile area within the area defined by the acoustic propagation profiles of the 2001 SCS ASIAEX cruise with a 5 km interval between profiles in this grid. Profiles acquired within the tighter grid have an orientation that is parallel and perpendicular to the acoustic propagation profiles of the 2001 SCS ASIAEX cruise. Acquisition of the tight grid provides an opportunity to begin to evaluate MINDDA for this type of system and provide the control for the range of the acoustics volume experiment. We also planned to collect cores for 2 days during the 2003 cruise to provide ground truth of the acoustic properties. We plan to address the objectives described below using the data acquired during the SCS cruise.

• Conduct seismic stratigraphic and facies analyses on the data to identify the nature of the heterogeneity of the stratigraphic architecture of the margin.

• Quantify the nature of horizontal and vertical seismic facies heterogeneity within a sequence stratigraphic context, and develop stochastic models of seismic facies heterogeneity produced under depositional conditions described for the SCS.

• Augment our assessment of the impact of the depositional processes from margins with extremely different boundary conditions on the stochastic models of vertical and horizontal distribution of seismic facies (and therefore geotechnical and acoustic properties).

• Assist with determination of the minimum data required to predict the distribution of seismic attributes on margins with various depositional boundary conditions. This will be accomplished by conducting sensitivity tests on survey spacing and associated changes in the distribution of mapped parameters.

APPROACH

The Carolina Seismic Imaging Lab (CSIL) of the University of North Carolina is researching the relationships between variations in sedimentary boundary conditions and the stratigraphy produced by these conditions. Limited work has been conducted on relating a quantified measure of the distribution of near-surface seismic facies and variability in depositional environment boundary conditions. The study area on the Western Pacific Continental Margin (WPCM) is a region with sediment supply ranging from very high (4 times the amount of sediment per year as the Mississippi River) to low/intermediate and large magnitude hydrodynamic sediment transport processes (tidal currents and large waves from typhoons and storms associated with the winter monsoon), so in some locales there may be a high degree of correspondence between the sedimentary processes active on the margin and the preserved stratigraphy. In other words it may be a situation where the sedimentary processes and recent stratigraphy may be in dynamic equilibrium. This situation may be rare today and it may be an "End-Member", but understanding this system is essential to understanding systems where the record of sedimentation is much less complete. In fact this area contrasts quite distinctively with many other continental margins (such as offshore Alabama, offshore Eel River, California, or offshore New Jersey).

The approach for this project is to: (1) acquire data from environments with a history of depositional boundary conditions ranging from intermediate to extreme, (2) conduct sequence stratigraphic analyses of these data to identify units deposited within the same interval of time, and (3) conduct quantitative seismic facies analyses on the data sets so that the variations in seismic facies within each time-slice can be tracked spatially and later subjected to Analysis of Variance, Q-mode factor analysis, binomial markov process analysis and Fuzzy Logic to identify non-random variations in seismic facies variability. This provides the stochastic model of spatial variability in acoustic property variability on the continental margin. We then test for sensitivity to survey spacing (MINDDA) by under and over sampling isochron maps of seismic facies and thickness of systems tracts at various intervals, overlaying the maps, measuring deviations in orientation of features, and their spatial magnitude and conducting statistical tests to determine when the differences are significant. We are conducting similar analyses when comparing the near-surface sonar facies distributions of the “end-member” continental margins.

We proposed to collect high-resolution seismic data (1,000 to 4,000 Hz. with 0.5 to 1 meter resolution) using 15 cubic inch water guns and 50 cubic inch Generator Injector air guns and ITI solid streamers and our digital acquisition and real-time processing system. We acquired extremely high-resolution digital chirp sub-bottom (2,000 to 8,000 Hz. with 0.1 to 0.5 meter resolution) and side-scan sonar data for geologic analysis with our Datasonics SIS-1000 system. We also collected cores to provide ground truth for acoustic properties and to provide insight on geologic processes. We (Dr. Tien NSYSU) borrowed an apparatus for measuring sound velocity of sediment in cores so we could measure sound velocities of sediment in cores on the ship. We will do additional measurements of other geotechnical attributes in the lab. Seismic stratigraphic and facies analyses are being conducted using Seisworks 2-D and the Kingdom Suite software. The results of these analyses will be subjected to our principal components and Markov analyses and MINDDA to help establish the linkage between process-response relationships and spatial distribution of acoustic properties.

WORK COMPLETED

• We acquired 1,945 km of high-resolution seismic data (Figure 1) and 665 km of chirp sub-bottom and side-scan sonar profiles in a grid that is parallel and perpendicular to depositional strike. Regional profiles that are strike-oriented are separated by approximately 15 km on the shelf and regional dip-oriented profiles are separated by 28 km. A very tight grid of data was acquired within a polygon with northern and western borders along the acoustic propagation lines from the 2,001 SCS-ASIAEX project. Strike-oriented profiles within the tight grid are separated by approximately 3.75 km on the shelf and dip-oriented profiles are separated by 7.5 km. Acquisition of chirp sub-bottom and side-scan sonar data was limited by loss of the chirp tow vehicle due to a cable parting. Coring activity was limited to 2 days due to poor weather and we were only able to collect 6 cores.

• Completed processing of seismic data.

• Completed loading seismic data into stratigraphic interpretation workstation and almost done with conducting stratigraphic analysis of the seismic data.

• In the midst of producing isopach and structure contour maps of important geologic intervals in the seismic data.

• Initiating file format conversion on chirp sonar data so that it can be processed and integrated with other chirp data from the area on a stratigraphic interpretation workstation.

• Begin geotechnical property measurements on cores and began textural analyses and core x-radiography Spring 2005.

RESULTS

A preliminary examination of the 1,945 km of high-resolution seismic data and 665 km of chirp sub-bottom and side-scan sonar data that were acquired during the survey reveals that the seafloor relief on the shelf is minimal. Sea level change in response to change in ice sheet volume created stratigraphic sequences in the area that are bounded by angular reflection terminations in some areas and high amplitude reflections in sights where the reflections are parallel. These angular reflection terminations and high amplitude reflections represent unconformities and are highlighted in Figure 2 by colored lines. Numerous sequences offlap toward the slope (Figure 2). The slope is dissected by canyons, creating complex relief on the slope and faults are also evident in the seismic data. In some locales on the shelf pinnacles that may be associated with carbonate reef systems are present beneath the seafloor. There are also reflections in the shelf stratigraphy that have variable amplitude and orientation and also lack continuity. We tentatively interpret these to be karst features created by weathering carbonate rocks in a humid climate during intervals when the shelf was subaerially exposed.

In the southwestern portion of the dataset, the morphology of the margin differs from that of typical passive margins. There is a shelf-slope break at about 120 m where the gradient of the margin increases, but then at about 200 m the gradient returns to value that is similar to the shelf (Figure 1 and 2). At about 600 meters the gradient increases again producing a second "shelf-slope" break. In the southwestern portion of the study area this produces a margin with a step-like morphology and a plateau between the shelf and the deep basin. The plateau provides an opportunity to examine sediment gravity flow stratigraphy that is usually only available at great depths in basins (Figure 2). Side-scan data from the slope reveals the presence of fields of large 2-D and 3-D bedforms in a number of locales. Sediment lying on the seafloor at the base of the first slope were and are reworked by strong slope parallel currents which produce the fields of dunes (Figure 2). Thus far we have not found these dunes in the older strata, so we conclude that the presence of this current is a relatively new phenomenon. In the South China Sea study area there is no evidence of the tidal ridges that are prominent features at the seafloor and at depth in the shelf strata of the East China Sea. Additional description of the stratigraphy and structure of the margin is forthcoming

IMPACT/APPLICATIONS

The scientific impact of this work is that it establishes the relationships between near-surface seismic/geotechnical property distribution and depositional boundary conditions associated with continental margins. This therefore leads to more reliable estimates of these properties in areas where it is either difficult to acquire such data, or it is necessary to design a survey that will quickly provide needed insight, with a given level of risk of a poor prediction. Establishing the nature of heterogeneity on the margin and the minimum quantity of data required to characterize the heterogeneity also leads to more successful design of transmission loss surveys and acoustics experiments on the role of bottom interaction on sound propagation in continental shelf environments. Understanding the nature of heterogeneity of margins obviously also has impact in areas such as oil and gas exploration and production, environmental waste containment, and of course defense related issues on continental margins.

RELATED PROJECTS

Our investigation is part of the South China Sea ASIAEX experiment. Data, analyses and makes will be used by the ASIAEX SCS acoustics experiment team (Dr. James Lynch of WHOI and Dr. Ching-Sang Chiu of the Naval Post-Graduate School and their colleagues) to constrain the impact of geological conditions on bottom interaction and sound propagation on the margin.

PUBLICATIONS/PRESENTATIONS

Papers

Ying Tsong Lin, James Lynch, Nick Chotiros, Chi-Fang Chen, Arthur Newhall, Altan Turgut, Steve Schock, Ching-Sang Chiu, **Louis Bartek**, Char-Shine Liu, An Estimate of Bottom Compressional Wave Speed Profile in the Northeastern South China Sea Using "Sources of Opportunity", IEEE Journal of Oceanic Engineering –Special Issue on Asian Marginal Seas. [Submitted, refereed]

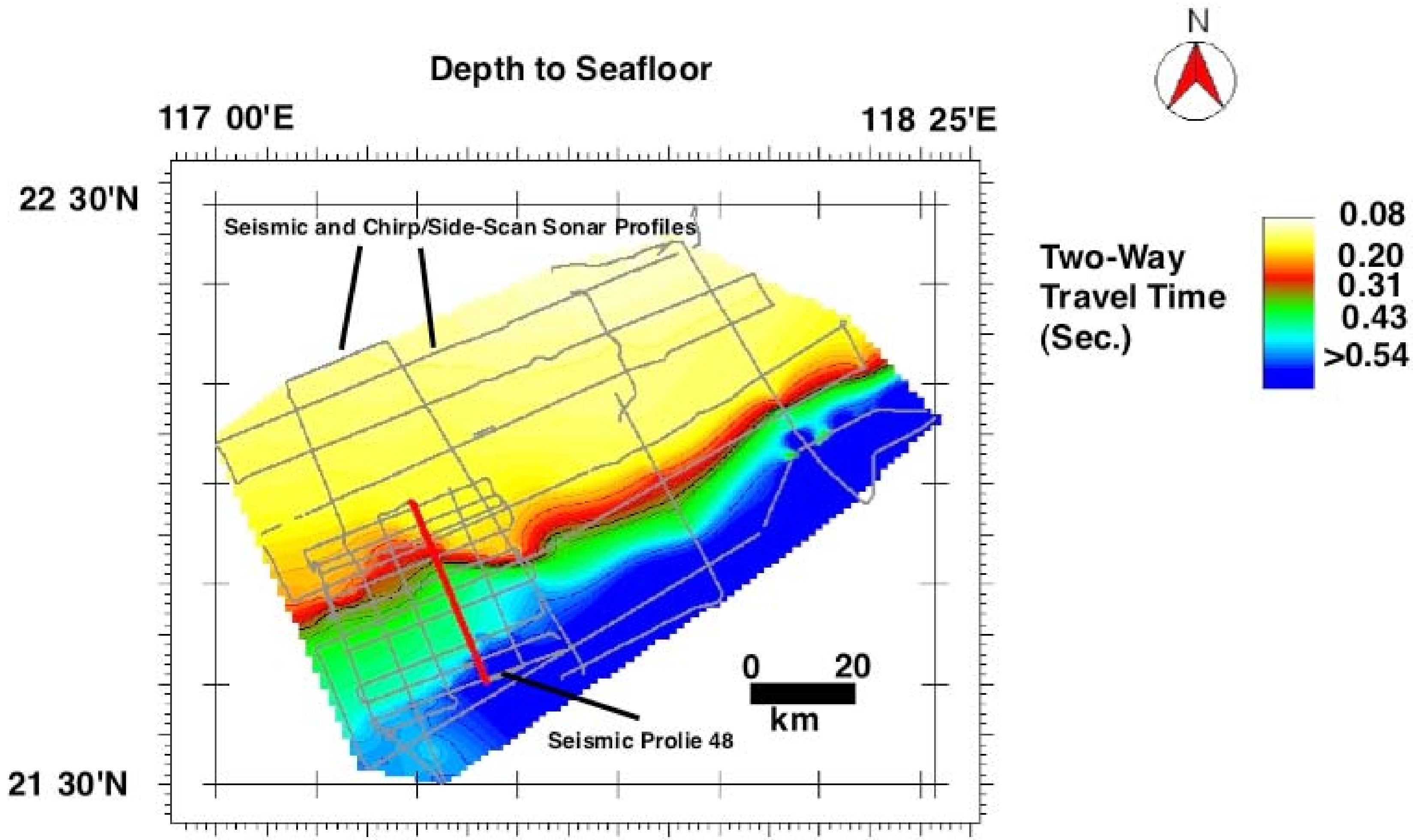

Figure 1: A map illustrating the location of Seismic and Chirp Sub-bottom nd Side-Scan Sonar profiles and seafloor bathymetry in the South China ea ASIAEX study area. Bathymetry is displayed in two-way travel time and derived from the location of reflections from the seafloor. Red line illustrates location of profiles displayed in Figure 2.

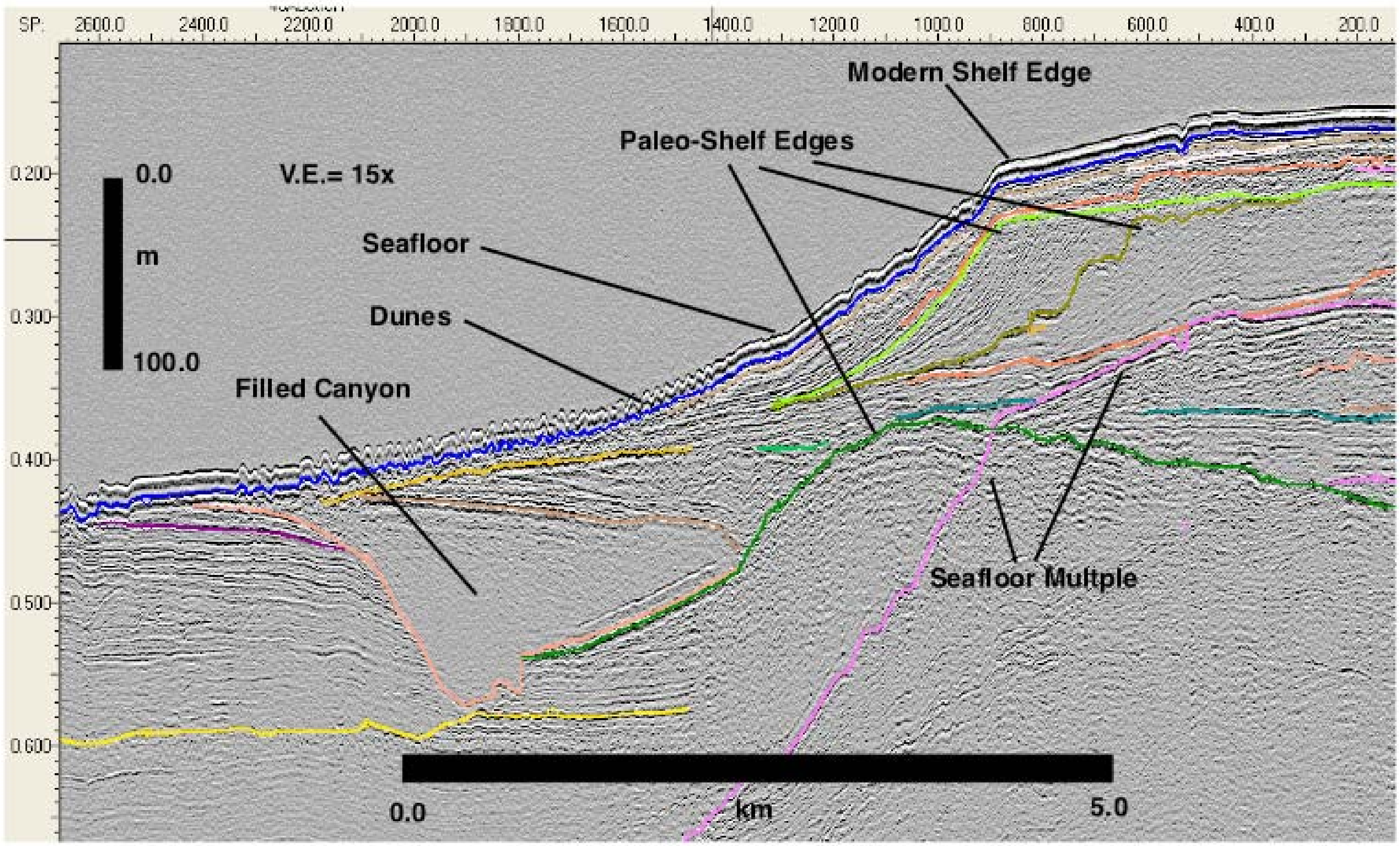

Figure 2: Interpretations of seismic profile 48 (see red line in figure 1). Colored lines denote unconformities. Maps depicting the relief on these unconformities as well as thicknesses of various units and seismic facies are being produced. Dunes noted on profile were initially identified on Side-Scan Sonar profiles and are associated with strong currents that flow parallel to the slope.